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Research Article

CT findings of pulmonary infection in patients with endotracheal intubation and mechanical ventilation

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Abstract

Purpose: To estimate the CT findings of clinically confirmed pulmonary infection in patients with endotracheal intubation and mechanical ventilation.
Materials and methods: This retrospective study enrolled 48 intubated adult patients with clinically confirmed pulmonary infection and CT examination after intubation in our hospital. Patients were further divided into two groups according to the risk of aspiration. Difference in clinical characters and imaging manifestations were compared between the two groups.
Results: The most common CT findings of pulmonary infection in intubated patients were GGO (93.8%) and consolidation (89.6%), followed by lung nodule (56.3%), pleural effusion (56.3%), thickened bronchial wall (50.0%), small airway disease (45.8%), lymphadenopathy (39.6%) and atelectasis (33.3%), but cavity (14.6%) and bronchiectasis (8.3%) were less common. The semi-quantitative scoring results showed significantly higher extent of lung lesions in gravity dependent region for patients in high-risk aspiration group. However, no significant difference was found in low-risk aspiration group. The difference in frequency of cross sectional distribution patterns between gravity dependent and independent region was also statistically significant for patients in high-risk aspiration group, but not in low risk aspiration group.
Conclusions: CT has advantage in assessment of lesions type, gravity dependent and cross sectional distribution of pneumonia in intubated patients.

Keywords: Pulmonary infection; Mechanical ventilation; Pneumonia; CT; Aspiration

1. Introduction

Pulmonary infection is common in intubated patients in ICU, with an approximate incidence of 20% and mortality of 30% [1]. It can be the reason of mechanical ventilation (MV) for respiratory failure developed from community-acquired pneumonia (CAP) or hospital-acquired pneumonia (HAP). While it can also be a complication of MV such as ventilator associated pneumonia (VAP) which lead to increased duration of MV, length of ICU stay and higher mortality [2,3]. The most common pathogens are Gram-negative bacilli, followed by Gram-positive bacteria, fungus and viruses. Co-infection, multidrug resistant Gram-negative bacteria or recurrent pneumonia are also not rare in intubated patients [4,5]. Aspiration-related pulmonary syndrome has contributed to the occurrence and development of pulmonary infection in intubated patients, because they are likely to have more aspiration risk factors such as disturbance of consciousness or sedation [6].

X-ray, CT and ultrasound are important imaging techniques in the diagnosis and management of pulmonary infection. In patients with MV, bedside X-ray has long been first choice to evaluate the emerging and changing of pulmonary infiltration. However, sometimes it's difficult to distinguish pulmonary infection from other pulmonary infiltrations by bedside X-ray,

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such as pulmonary edema, acute respiratory distress syndrome (ARDS), alveolar hemorrhage and atelectasis [7–9]. On this occasion, CT is preferred because of its ability to provide more information about the extent and distribution of lesions [7,10]. The aim of this study was to estimate the CT findings of clinically confirmed pulmonary infection in patients with endotracheal intubation and MV.

2. Materials and methods

From January 2014 to April 2016, 48 intubated patients with pulmonary infection were finally enrolled in our hospital (a tertiary teaching hospital with 1752 beds). Inclusion criteria were: 1) adult patients (≥18 years); 2) receiving endotracheal intubation and MV for respiratory failure or other reasons; 3) clinical diagnosed pneumonia; 4) chest CT performed after MV to evaluate the pneumonia. Pneumonia were diagnosed if new or progressive lung lesions including infiltrate, consolidation or cavity appeared on bedside radiographs and meeting at least two of the followings: temperature >38 °C or <36 °C; purulent sputum; white blood cell ≥12,000/μl or <4000/μl. Exclusion criteria were: a simultaneously progressing heart failure and pulmonary edema on CT; ARDS developed from other critical illnesses except pulmonary infection; other underlying lung diseases on CT (interstitial pneumonia, pulmonary neoplasm). This retrospective study was approved by our hospital's Institutional Review Board and informed consent was waived for its retrospective nature.

2.1. Clinical and laboratory data

Clinical records were acquired from the Electronic Medical Record (EMR) in our hospital. Bacterial causative pathogens were mainly determined by microscopic examinations and semi-quantitative cultures of low respiratory track samples, sometimes by cultures of blood or pleural fluid samples, serological studies and urinary antigen tests. All patients had sputum smear with Gram's stain, as well as sputum or bronchoalveolar lavage (BAL) semi-quantitative culture for bacteria. Laboratory tests of acid-fast bacillus, virus, fungi and atypical pathogens (*Mycoplasma pneumoniae*, *Chlamydia pneumoniae* and *legionella*) were performed according to clinical need. Above-mentioned pathogens isolated no earlier or later than 3 days of the chest CT were recorded as the causal pathogens of CT findings. Bedside chest radiography was performed routinely. Antimicrobial treatment could have begun before the chest CT, but was not changed in the past 3 days of the causative etiological examination.

As a great proportion of patients in our study had risk or history of aspiration, two groups (high- and low-risk aspiration group) were further divided according to aspiration risk. In high-risk aspiration group, patients should have at least one of the following conditions: a clear recent history of macroaspiration; dysphagia caused by cerebrovascular disease; dementia; Parkinson's disease or neuromuscular disorders; long-term bedridden; general anesthesia in surgery. In low-risk aspiration group, patients should have none of the above-mentioned conditions.

2.2. CT scan protocol

Only the first chest CT scans after MV were analyzed. All scans were acquired at end inspiration on a 64-MDCT dual source scanner (SOMATOM Definition Flash; Siemens Healthcare, Forchheim, Germany), with a mean interval time of 9 days (range, 0–45 days) after intubation. Contrast enhancement CT was not used in most cases. The entire lung from the apex to the base was scanned using the following CT parameters: 120 kVp and 110 mA (quality ref. mA) with CARE Dose 4D technique; pitch 1.05; collimation 0.6 mm. Images were reconstructed by using convolution kernel lung window B70f and soft tissue window B35f, slice interval 0.7 mm and slice thickness 1.0 mm. Images were transmitted to GE AW4.5 workstation for further analysis.

2.3. CT image analysis

The CT images were reviewed by two pulmonary radiologists in consensus. These two radiologists were blinded to patients' clinical and laboratory data. Lung parenchyma was viewed with a window level of −600 HU and a window width of 1600 HU. Soft tissue was viewed with a window level of 40 HU and a window width of 400 HU.

A three-step CT image analysis was applied. First step was the identification of pulmonary infection lesions. The predefined lesions were as follows: consolidation; ground-glass opacity (GGO); nodule; cavity; small-airway disease (centrilobular micronodules, tree-in-bud pattern, bronchiolectasis, mosaic attenuation); thickened bronchial wall; bronchiectasis; atelectasis; lymphadenopathy; pleural effusion. Second step was to compare the extent of pulmonary infection between gravity dependent and independent region. The right and left lung were separately analyzed. For the right lung, the gravity dependent region included four segments: posterior segment of right upper lobe, apical segment of right lower lobe, basal segment's anterior and posterior part of right lower lobe. Relatively, four segments of gravity independent region were apical segment and anterior segment of right upper lobe, medial segment and lateral segment of right middle lobe. For the left lung, the gravity dependent four segments were: apicoposterior segment' posterior part of left upper lobe, apical segment of left lower lobe, basal segment's anterior and posterior part of left lower lobe. And gravity independent four segments were: apicoposterior segment's apical part of left upper lobe, anterior segment of left upper lobe, superior and inferior lingular segments of left upper lobe. For a unilateral lung, in gravity dependent and independent region respectively, a semi-quantitative scoring method (0–4 points) by summing up the number of involved pulmonary segments in that region was used. Involved segment was defined to have any kinds of lesions above-mentioned. Third step was to find the primary cross sectional distribution patterns of lesions in gravity dependent and independent region of bilateral lungs.

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The distribution patterns were divided into 5 types: negative; bronchocentric distribution; peripheral distribution; diffuse distribution; random distribution.

2.4. Statistical analysis

All statistical analyses were completed by SPSS statistical software (version 19.0, IBM, SPSS Inc, Armonk, NY). Continuous variables were expressed as mean ± SDs and compared by Student *t* test between the high- and low-risk aspiration groups. Categorical variables were presented as frequency (percentage) and compared by using χ^2 or Fisher exact test between the two groups or regions. The semi-quantitative scoring results in gravity dependent and independent region of the unilateral lung were compared by Wilcoxon signed-ranks test. $P < 0.05$ was considered to have statistically significant difference.

3. Results

3.1. Clinical characteristics of patients

48 consecutive patients were finally included and further divided into high-risk aspiration group (n = 39) and low-risk aspiration group (n = 9). Patients' demographic and clinical characteristics were summarized in Table 1. Most cases were males (31/48 cases, 64.6%), with an average age 68.5 years old (range, 18–94 years old). *Acinetobacter baumannii* (21 cases, 43.8%) was the most common bacterial pathogen, followed by *Pseudomonas aeruginosa* (7 cases, 14.6%) and *Klebsiella pneumoniae* (7 cases, 14.6%). No significant differences in age, WBC, Temperature, heart failure (%), male (%), purulent sputum (%), bacterial pathogens (%) were found between the high- and low-risk aspiration group. However, surgery or other critical illness as reason for MV and

Table 1
Clinical characteristics of patients n (%).

	Total	High-risk aspiration group	Low-risk aspiration group	*P* value
No. of patients	48	39(81.3)	9(18.7)	
Age, mean ± SD (y)	68.5 ± 40.0	69.1 ± 20.4	66.3 ± 19.4	0.72
Male	31(64.6)	27(69.2)	4(44.4)	0.31
Heart failure	10(20.8)	8(20.5)	2(22.2)	1.00
WBC count(/μl)	13.0 ± 6.2	13.0 ± 6.4	12.9 ± 6.0	0.94
Neu (%)	83.3 ± 8.4	84.1 ± 8.0	80.0 ± 9.5	0.18
Temperature(°C)	37.9 ± 0.8	37.9 ± 0.79	37.9 ± 1.0	0.92
Reason for MV				0.04*
Lung disease	35(72.9)	26(66.7)	9(100)	0.11
Surgery	7(14.6)	7(17.9)	0(0)	0.40
Other critical illness	6(12.5)	6(15.4)	0(0)	0.49
Respiratory failure				0.03*
Without RF	7(14.6)	7(18.0)	0(0)	0.40
Hypoxemic RF	16(33.3)	10(25.6)	6(66.7)	0.05
Hypercapnia RF	25(52.1)	22(56.4)	3(33.3)	0.38
Purulent sputum	24(50)	19(48.7)	5(55.6)	1.00
Bacteria				
Klebsiella pneumoniae	7(14.6)	6(15.4)	1(11.1)	1.00
Staphylococcus aureus	5(10.4)	5(12.8)	0(0)	0.57
Pseudomonas aeruginosa	7(14.6)	5(12.8)	2(22.2)	0.84
Acinetobacter baumannii	21(43.8)	16(41.0)	5(55.6)	0.68
Others	5(10.4)	4(10.3)	1(11.1)	1.00
Fungi	7(14.6)	3(7.7)	4(44.4)	0.022*

*Means $P < 0.05$; SD = standard deviation; WBC = white blood cell; Neu(%) = neutrophil(%); MV = mechanical ventilation; RF = respiratory failure.

Table 2
CT findings of pulmonary infection in patients with MV n (%).

	Total (n = 48)	High-risk aspiration group (n = 39)	Low-risk aspiration group (n = 9)	*P* value
Consolidation	43(89.6)	35(89.7)	8(88.9)	1.00
GGO	45(93.8)	36(92.3)	9(100)	1.00
Lung nodule	27(56.3)	21(53.8)	6(66.7)	0.74
Cavity	7(14.6)	4(10.3)	3(33.3)	0.21
Small airway disease	22(45.8)	17(43.6)	5(55.6)	0.78
Thickened bronchial wall	24(50.0)	19(48.7)	5(55.6)	1.00
Bronchiectasis	4(8.3)	3(7.7)	1(11.1)	1.00
Atelectasis	16(33.3)	15(38.5)	1(11.1)	0.24
Lymphadenopathy	19(39.6)	15(38.5)	4(44.4)	1.00
Pleural effusion	27(56.3)	21(53.8)	6(66.7)	0.74

GGO = ground-glass opacity.

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Fig. 1. *Acinetobacter baumannii* pneumonia in a 34 years old man with MV for cerebral hemorrhage and hypercapnia respiratory failure. CT images show tree-in-bud opacities (small airway disease) and patchy GGOs with bronchocentric distribution in right upper lung. There is also bilateral lower lung atelectasis.

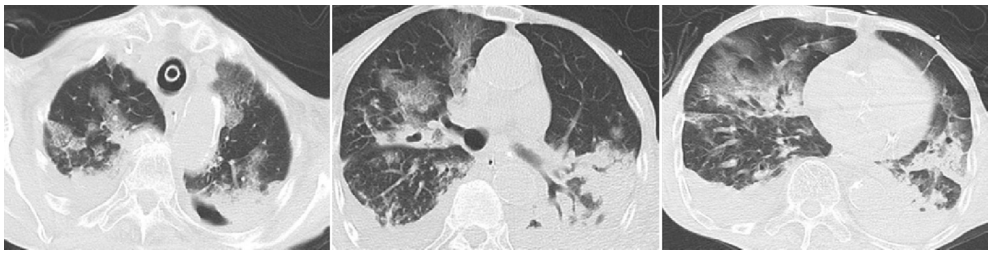

Fig. 2. *Klebsiella pneumoniae* and *Staphylococcus aureus* co-infected pneumonia in an 89 years old man with MV for severe pneumonia and hypoxemic respiratory failure. CT images show multiple patchy GGOs and consolidation with bronchocentric distribution in both upper lungs and diffuse distribution in left lower lung. Several cavities can be seen in regions of consolidation.

Table 3
Semi-quantitative scoring results in gravity dependent and independent region.

	Gravity dependent region	Gravity independent region	*P* value
Total (n = 48)			
Right lung	3.29 ± 1.17	2.52 ± 1.51	<0.001*
Left lung	3.08 ± 1.14	2.29 ± 1.44	0.001*
High-risk aspiration group (n = 39)			
Right lung	3.41 ± 1.07	2.51 ± 1.50	<0.001*
Left lung	2.51 ± 1.50	2.05 ± 1/47	<0.001*
Low-risk aspiration group (n = 9)			
Right lung	2.78 ± 1.48	2.56 ± 1.67	0.32
Left lung	3.00 ± 1.12	3.33 ± 0.71	0.53

*Means $P < 0.05$.

hypercapnia RF were more frequently observed in high-risk aspiration group ($P = 0.04$, $P = 0.03$, respectively). Fungi pneumonia was significantly more common in low-risk aspiration group ($P = 0.022$).

3.2. CT findings

CT findings of pulmonary infection in all cases (n = 48) are listed in Table 2. GGO (93.8%) and consolidation (89.6%) were the most common CT findings (Figs. 1 and 2). About half of the cases showed nodule (56.3%), thickened bronchial wall (50.0%), pleural effusion (56.3%), small airway disease (45.8%). Other relatively less common CT findings included lymphadenopathy (39.6%), atelectasis (33.3%), cavity (14.6%) and bronchiectasis (8.3%). Although a mildly lower frequency of cavity (10.3% &33.3%) and a higher frequency of atelectasis (38.5% & 11.1%) were seen in the high risk aspiration group, actually no significant difference in CT findings was found between these two groups.

Semi-quantitative scoring results were separately compared for right and left lung (Table 3, Fig. 3). For all patients (n = 48), scoring results were significantly higher in gravity dependent region than in gravity independent region, in both right lung (3.29 & 2.52, $P < 0.001$) and left lung (3.08 & 2.29, $P = 0.001$). Similarly, in high-risk aspiration group (n = 39), scoring results were also higher in gravity dependent region, in both right lung (3.41 & 2.51, $P < 0.001$) and left lung(2.51 & 2.05, $P < 0.001$) (Fig. 3). However, in low-risk aspiration group (n = 9), no statistically significant difference of the scoring results was found between the gravity dependent and independent region, in both right ($P = 0.32$) and left lung ($P = 0.53$).

The difference in frequency of cross sectional distribution between gravity dependent and independent region was statistically significant, both for all patients ($P = 0.006$) and patients in high-risk aspiration group ($P = 0.01$) (Table 4). In gravity dependent region, bronchocentric and diffuse distribution were the two most common distribution patterns (33.3–37.5%, 33.3–35.9%, respectively), compared to bronchocentric distribution (61.5–62.5%) most frequently found in gravity independent region. However, for the low-risk aspiration group, the frequency of cross sectional distribution showed no significant difference in gravity dependent and independent region, in which bronchocentric distribution was the most common distribution pattern (55.6–66.7%).

4. Discussion

48 intubated patients with clinical diagnosed pneumonia were enrolled in this retrospective study. Most cases were

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Fig. 3. *Acinetobacter baumannii* and *Klebsiella pneumoniae* co-infected pneumonia in an 84 years old man with MV for hypoxemic respiratory failure. He had a history of cerebral infarction and long-term bed-ridden. CT images show a gravity dependent distribution of consolidation, GGOs and cavities in left upper and bilateral lower lungs. Semi-quantitative scoring results in gravity dependent and independent region: 3, 0 for right lung and 4, 2 for left lung, respectively.

males (31/48 cases, 64.6%), with an average age 68.5 years old (range, 18–94 years old). The most common reason for MV was lung diseases. Hypercapnia respiratory failure and accompanied heart failure were found in 52.1% and 20.8% of patients, respectively.

For intubated patients, studies had reported that CT could assist in the evaluation of pneumonia in ICU [9–13]. In our study, GGO (93.8%) and consolidation (89.6%) were the most common CT findings of pulmonary infection, followed by lung nodule (56.3%), pleural effusion (56.3%), thickened bronchial wall (50.0%), small airway disease (45.8%), lymphadenopathy (39.6%) and atelectasis (33.3%). Cavity (14.6%) and bronchiectasis (8.3%) were relatively less common. The results were in agreement with the study by Okada et al., in which GGO (100%) and consolidation (91.4%) and pleural effusion (53%) were most common CT findings in patients with *K. pneumoniae* pneumonia [14]. Study by Omeri et al. had also shown consolidation, bronchial wall thickening, cavity and pleural effusion as the most common imaging manifestations of *P. aeruginosa* pneumonia [15].

The etiological diagnosis of Gram-negative bacillus pneumonia took the largest proportion in our study. Gram-negative bacilli are not common pathogens of CAP, but are more likely related to hospital or ICU acquired infection, even VAP [16,17]. Besides, as culture results of low respiratory track samples were recorded as causal pathogens if only they were no earlier or later than 3 days of CT examination, it's worth suspecting if these Gram negative bacilli were the only causal pathogens responsible for the imaging manifestations. Although neither viral pneumonia nor atypical pathogenic pneumonia was etiological diagnosed in this study, a co-infection could not be excluded. Studies had reported the overlap of CT findings in viral pneumonia, atypical pathogenic pneumonia and bacterial pneumonia. Viral pneumonia seemed to have CT findings of GGO, consolidation and small airway disease, with a bronchocentric or random distribution [18]. For atypical pathogenic pneumonia, the most common CT findings were consolidation, GGO and nodule [19].

Table 4
Cross sectional distribution pattern in gravity dependent and independent region n (%).

	Gravity dependent region	Gravity independent region	*P* value
Total (n = 48)			0.006*
Negative	3(6.3)	8(16.7)	0.11
Bronchocentric	18(37.5)	30(62.5)	0.014*
Peripheral	6(12.5)	1(2.1)	0.12
Diffuse	16(33.3)	6(12.5)	0.015*
Random	5(10.4)	3(6.3)	0.71
High-risk aspiration group (n = 39)			0.007*
Negative	2(5.1)	6(15.4)	0.23
Bronchocentric	13(33.3)	24(61.5)	0.013*
Peripheral	6(15.4)	1(2.6)	0.11
Diffuse	14(35.9)	5(12.8)	0.018*
Random	4(10.3)	3(7.7)	1.00
Low-risk aspiration group (n = 9)			0.54
Negative	1(11.1)	2(22.2)	1.00
Bronchocentric	5(55.6)	6(66.7)	1.00
Peripheral	0(0)	0(0)	1.00
Diffuse	2(22.2)	1(11.1)	1.00
Random	1(11.1)	0(0)	1.00

*Means $P < 0.05$.

Although CT has advantages in revealing pulmonary infection, it's still complicated to make sure what the CT findings really pointed to. Many factors could affect the analysis of pulmonary infection. In our study, pulmonary edema, ARDS developed from illnesses other than pulmonary infection, underlying lung diseases such as interstitial pneumonia or neoplasm were excluded. However, previous bronchiectasis, chronic bronchitis, thicken bronchial wall related to aging or asthma were still confounding factors which could make the analysis controversial. Besides that, ventilator associated pneumonia, post operative pneumonia and aspiration pneumonia are all common complications in intubated patients [20]. Possibility of co-infection can make the analysis more difficult.

As intubated patients are frequently with dysphagia or coma, they have more risks to aspirate microorganisms colonizing in oropharynx. Micro-aspiration can also play a role in the procedure of pulmonary infection in intubated patients, in which leakage from around the cuff and microbial biofilm of tube facilitates the colonization and infection of pathogens [21–23]. Bacterial pneumonia secondary to aspiration can occur. CT has advantage over bedside X-ray because it can show the distribution of pulmonary lesions clearly. However, few studies had evaluated the distribution of pulmonary infection lesions in gravity dependent and independent region in intubated patients. In our study, most patients (39/48, 81.3%) were assigned to the high-risk aspiration group, which was related to the design that patients with only one risk factor mentioned above would be assigned to high-risk aspiration group. The semi-quantitative scoring results were significant

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higher in gravity dependent region than in gravity independent region for all patients and patients in high-risk aspiration group, but not in the low-risk aspiration group. Our results support the opinion that aspiration pneumonia is more likely to appear in gravity dependent region.

There are several limitations in our study. First, patients' number was small, especially for the low-risk aspiration group. It is related to the relatively harsh conditions for low-risk aspiration group and the short period for patient-s'inclusion. Second, this study was conducted in a single center and not all intubated patients with pulmonary infection had performed chest CT, so bias may exist in the results. Third, no diagnosis of viral pneumonia was made in our study, which may be related to a low frequency of reverse-transcription polymerase chain reaction (RT-PCR) test performed. Actually, viral pneumonia is not rare in patients requiring ICU admission, so further improvement is advised [24]. Forth, no etiology diagnosis of CAP such as streptococcus pneumoniae pneumonia or haemophilus influenzae pneumonia was made. It may be associated to the long interval time between intubation and CT examination. As we only recorded the results of sputum or BAL culture no earlier or later than 3 days of CT examination, the original pathogenic bacteria may be replaced by Gram-negative bacilli due to ICU acquired infection.

In conclusion, CT has advantage in the assessment of lesions type, gravity dependent and cross sectional distribution of pulmonary infection in intubated patients. Aspiration associated pathogenesis may account for the significant difference in the extent and cross sectional distribution patterns between the gravity dependent and independent region in patients with high risk of aspiration.

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